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DESIGN, DEVELOPMENT, MANUFACTURE, AND DELIVER NEW CONCEPTS FOR HIGH ENERGY RATE FORMING SYSTEM

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Manufacturing Research Department

RAC 2788-2

A 28" dome was completely formed using the 12" Electromagnetic Transducer. The overall time is faster than E. B. W. by a factor of 2. 5. The total energy required was higher by a factor of 10. An induced voltage probe indicates that work is transferred during the first 1/4 cycle.

Republic Aviation Corporation
Farmingdale, New York

Design, Development, Manufacture, and Deliver
New Concepts for High Energy Rate Forming System

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General Discussion

1.0 During the third quarter of this contract, two 28" domes were formed using a 12" pancake coil Electromagnetic Transducer (see Fig. 1). Using the same equipment (die, cap. bank etc.) with E. B. W. a 28" dome was also formed for comparison (see Fig. 2). The time required to form the 28" dome with the E. M. T. (Electromagnetic Transducer) was less by a factor of 2.5 (14 minutes for E. M. T. versus 40 minutes for E. B. W.). The total energy requirement, however, was more by a factor of 10 (see Fig. 3). These results, however, should not be considered final since it is possible that a larger transducer (i.e. 24" pancake coil) may be considerably more efficient for the same size dome.

The transducer must be considered in two parts: a) the conversion of energy from electrical to potential through the driver plate and b) the conversion of energy from potential in the pressure wave to strain energy in the workpiece.

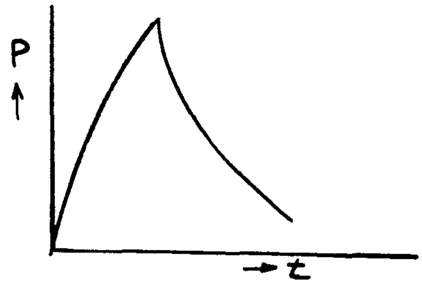
It was found that the conversion from electrical to potential energy was 20-37% efficient.

The conversion from potential to strain energy was in the order of 5%. It must be emphasized again, however, that the main purpose was to develop the transducer. In the second phase of this program, a 24" pancake coil will be used and the E. M. T. as the source of the pressure wave will be larger and, it is expected, more efficient; the details of this set-up will be given below.

The E. M. T. was mechanized; the driver plate is reset by two air cylinders (see Fig. 4). This considerably advanced the E. M. T. method over the E. B. W.

Theoretically, the loading side of the pressure wave was calculated (Fig. 5) and compared with the experimental.* The theoretical was found higher by 16%: the difference, it is believed, is due to the opposing force which prevents the plate from falling. In the unloading side, the decay may be due to: a) the water resistance alone, and b) the attraction by the reversed magnetic field as well as the water resistance. In case a), the decay will be exponential as shown on the following page.

* See January monthly letter



In case b), the decay must follow the loading rate in the reverse manner (see Fig. 6). Quite often however, the decay begins exponentially and then it is interrupted by a magnetic attraction as well as by the rough and uneven circumferential forces that initially hold the plate up against the coil (see diagram below).

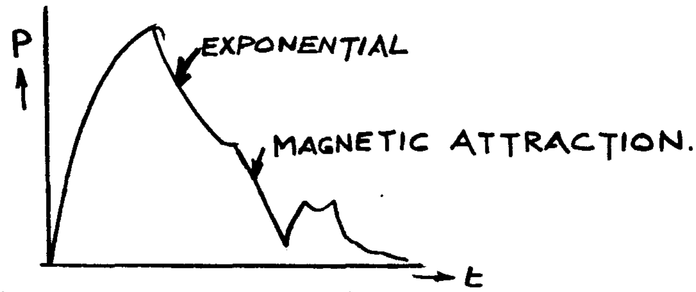
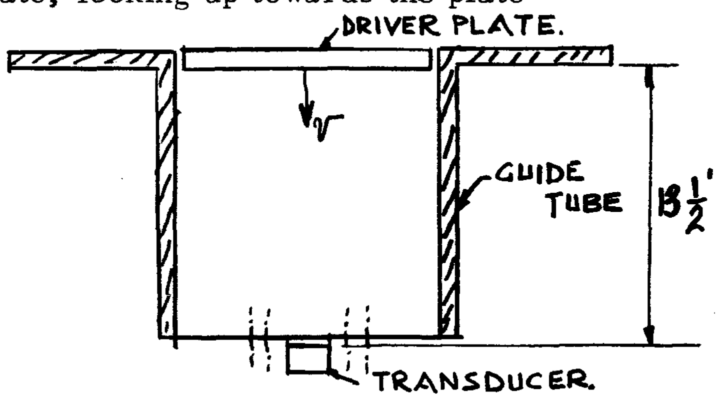


Figure 7 shows the experimental case.

In both Figures (6) and (7) the pressure pick-up was placed at 13.5 inches below the plate, looking up towards the plate



The time delay in the pressure trace, therefore, is due to the time it takes the wave to travel 13 1/2 inches in water. (i.e. $\frac{13.5}{4700 \times 12}$ $= 2.4 \times 10^{-4}$ sec. or 240 μsec. The experimental records show 260μsec.).

The transducer was originally located on the side of the guide tube, 2" from the driver plate facing inwards. Comparison between the pressure profile records taken in this manner and those taken with transducer looking up towards the plate, showed no difference. The records taken from the side however, had an unjustifiable delay of 300 μsec.

2.0 From the theoretical analysis of the E.M.T., described in the last quarterly report, it was found that the total induced voltage in the driver is given by:

$$V = -\frac{\mu I r}{\bar{z}} \frac{d\bar{z}}{dt} - \mu r \ln \bar{z} \frac{dI}{dt} \quad . \quad . \quad . \quad . \qquad (1)$$

where μ = electrical permeability
r = mean radius of the coil
I = instantaneous current
$\bar{z}$ = distance from the coil (DIMENSIONLESS $\frac{z}{z_0}$)
and t = time

Furthermore, it is known that

$$I = \frac{E_0}{wL} e^{-\frac{R}{2L}t} \sinh wt \quad . \quad . \quad . \qquad (2)$$

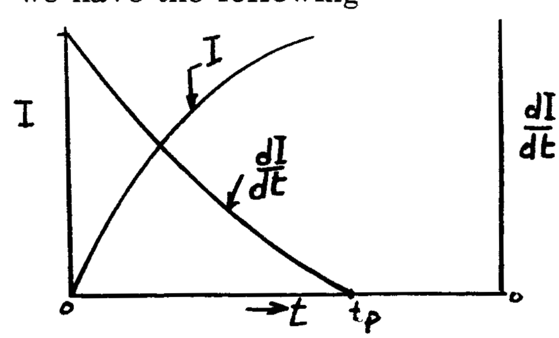
and $$\frac{dI}{dt} = \frac{E_0 w}{wL} e^{-\frac{R}{2L}t} \cosh wt - \frac{E_0 R}{(wL)2L} e^{-\frac{R}{2L}t} \sinh wt \, . \qquad (3)$$

or $$\frac{dI}{dt} = \frac{E_0}{wL} e^{-\frac{R}{2L}t} \left(w \cosh wt - \frac{R}{2L} \sinh wt \right) \quad . \quad . \qquad (4)$$

thus at t=O $\quad \frac{dI}{dt} = \frac{E_0 w}{wL} = \frac{E_0}{L}$

at t_p when I is a maximum, $\frac{dI}{dt} = O$

Thus, druing the first quarter of the cycle when the system is overdamped, we have the following



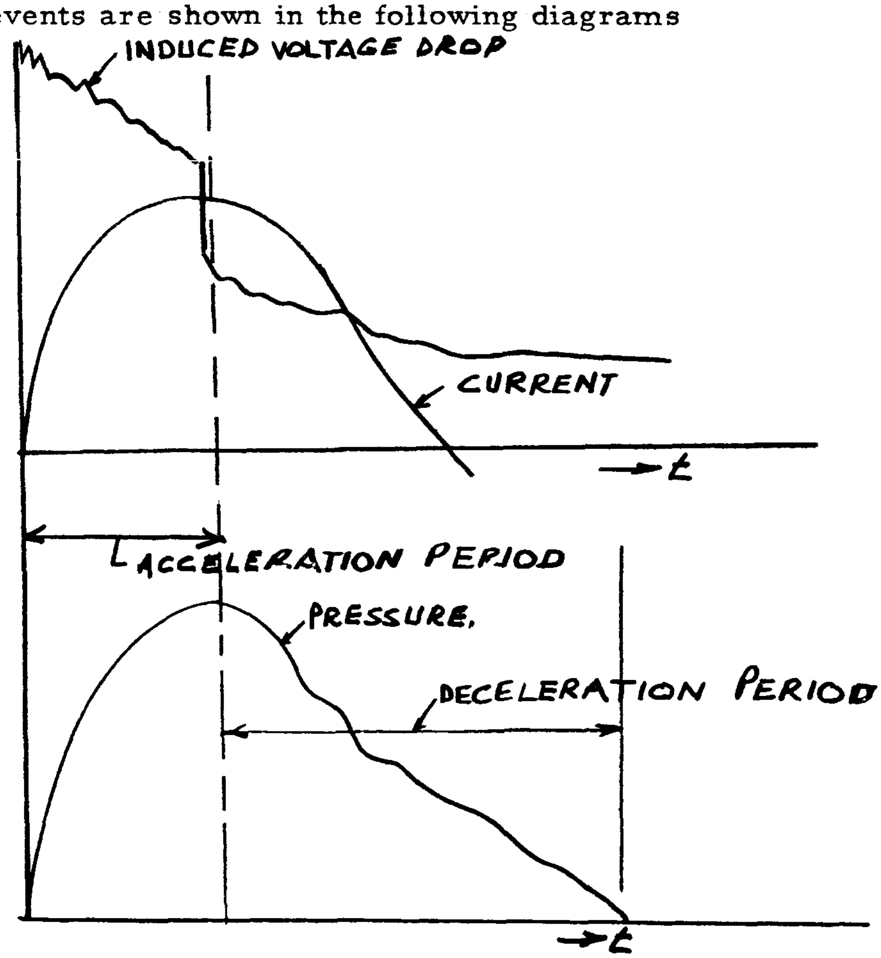
In addition, during the initial stages of motion, $\frac{d\bar{z}}{dt}$ (velocity of plate) is nearly zero, I is very small, $\bar{z}$ is finite (thickness of coil insulation); thus, the induced voltage is given mainly by

$$V = -\mu r \ln \bar{z} \frac{dI}{dt} \quad . \quad . \quad . \quad . \qquad (5)$$

Furthermore, as the plate moves and $\frac{d\bar{z}}{dt}$ and I increase, they are positive; $\frac{dI}{dt}$ is also positive. Hence, the terms $\frac{\mu I r}{\bar{z}} \frac{d\bar{z}}{dt}$ and $\mu r \ln \bar{z} \frac{dI}{dt}$ have the same sign.

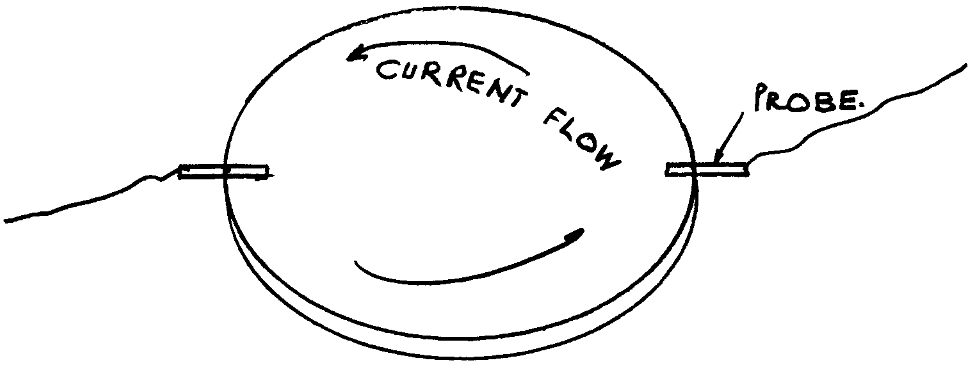
At the point where the acceleration phase ends, and the deceleration phase begins $\frac{dV}{dt}$ changes sign. From tests, which will be discussed later, it is found that this point also corresponds to the peak of the current trace for 16 KV of the 240 μf capacitor bank.

These events are shown in the following diagrams



Experimentally, these events are shown in Figure 8.

The method of detection was described in the last monthly report; it consists mainly of two probes diametrically positioned on the driver plate.



It is worth noting here that the plate moves only 0.05 in. and the brass probes are flexible enough to follow.

Theoretically, the events can be illustrated as follows.

Differentiate equation (1) thus:

$$\frac{dV}{dt} = -\mu\frac{r}{\bar{z}}\frac{dv}{dt} + \frac{\mu r}{\bar{z}^2}v - \mu\frac{rv}{\bar{z}}\frac{dI}{dt} - \mu r \ln\bar{z}\,\frac{d^2I}{dt^2} \quad . \quad . \quad (6)$$

where $\frac{d\bar{z}}{dt} = v$ = velocity

and $\bar{z} = \frac{z}{z_0} \doteq 1$

It is apparent that if the terms $\frac{dv}{dt}$, $\frac{dI}{dt}$ and $\frac{d^2I}{dt^2}$ are all zero at the same time, a sudden drop in V will take place (see Fig. 8). This was the case at 16KV; at lower capacitor bank voltages, $\frac{dv}{dt}$ is not zero when $\frac{dI}{dt}$, and $\frac{d^2I}{dt^2}$ are zero, but it is zero later.

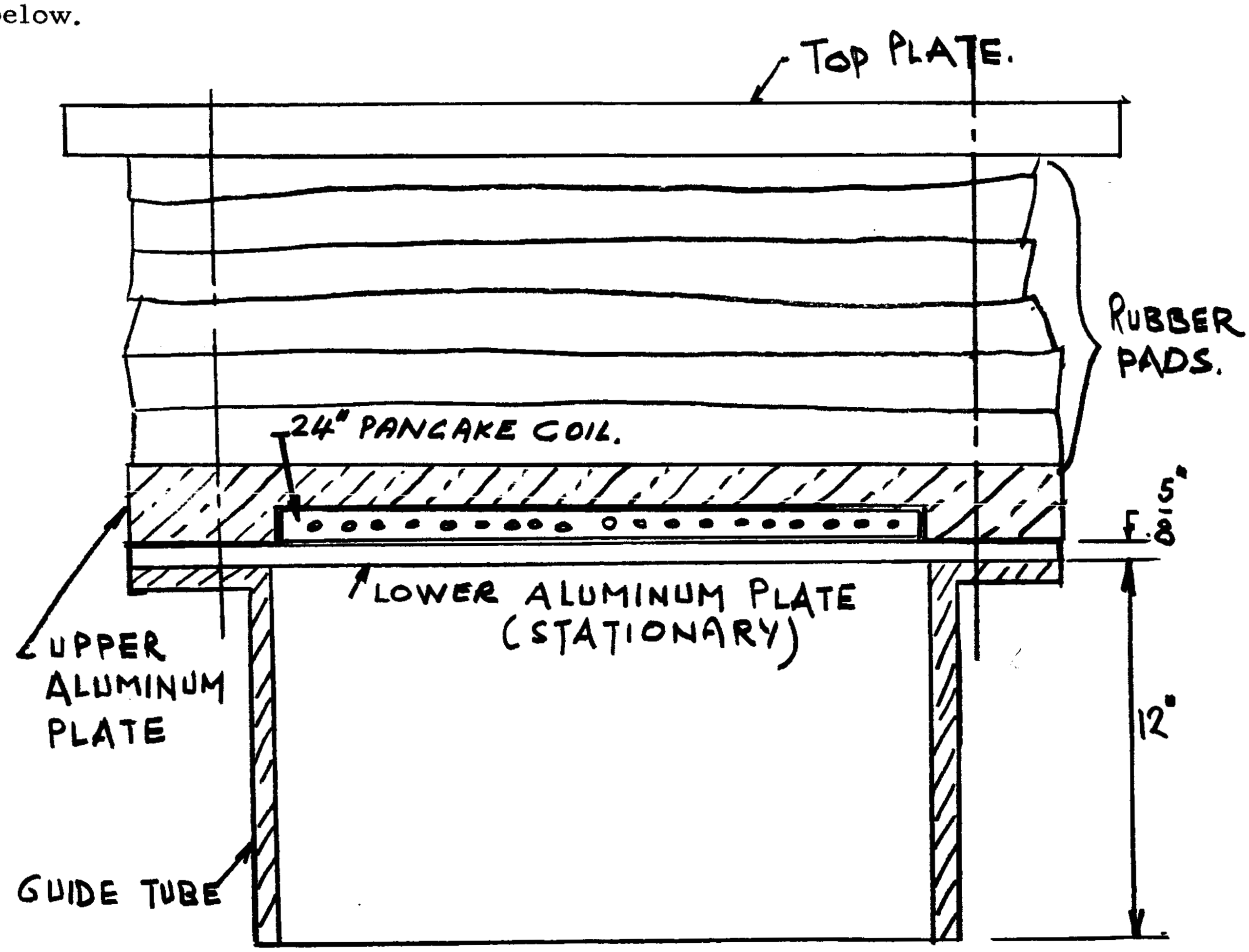
This is due to the water resistance which is a function of the velocity (i.e. $P=\rho.c.v$). Thus it was apparent that the drop in induced voltage was due mainly to changes in velocity $\frac{dv}{dt}$ rather than $\frac{dI}{dt}$ and $\frac{d^2I}{dt^2}$.

Now, since the acceleration phase ends at the same time that the current reaches its peak, any subsequent current changes do not appear to contribute to the energy transferred to the pressure wave. In other words, the energy contained in the pressure wave was transferred during the first 1/4 cycle.

<u>24" Pancake Coil Set-up</u>

The 24" pancake coil was built in the same way that the 12" coil was built.

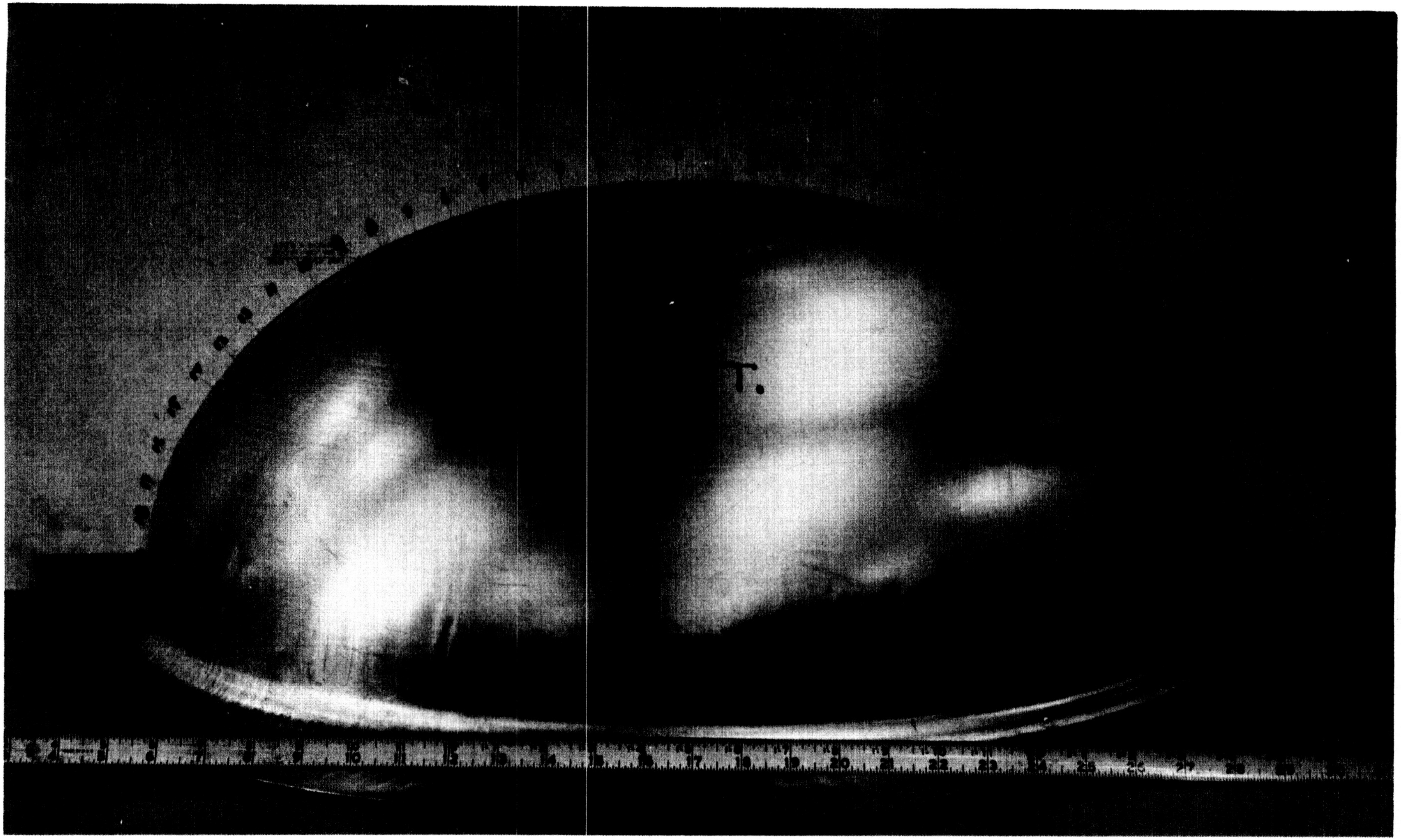
The assembly is also the same with one exception: instead of the driver plate, a stationary plate is used. The set-up is shown in the schematic below.



The 24", 40 turn coil was constructed (Fig.9, '0). The guide tube and the lower aluminum plate are also fabricated. The final assembly will be used with the 28" die to form a dome. The set-up will be tested up to 100,000 joules with the 960 µf capacitor bank.

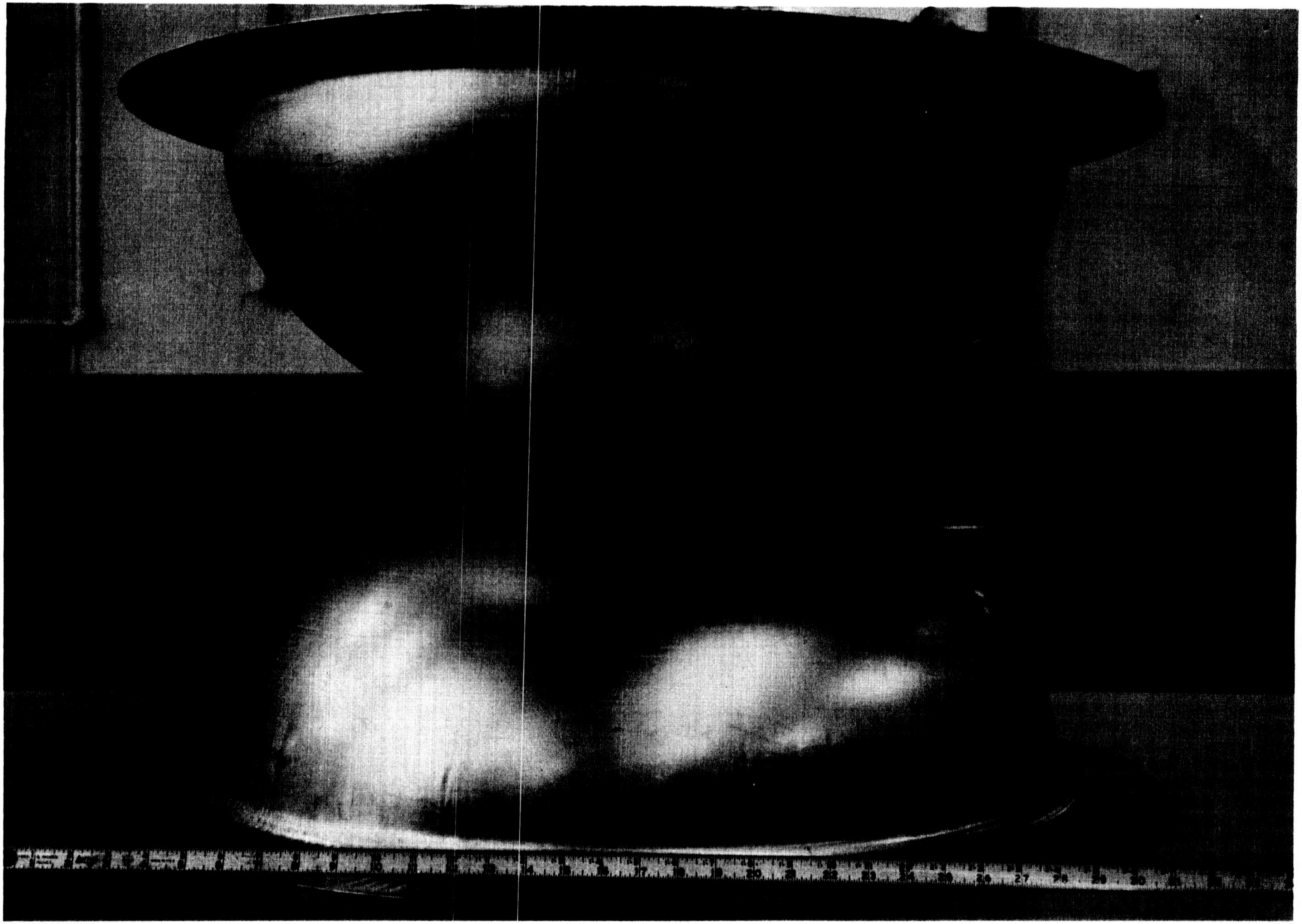
Anticipated work during April 1 to May 1, 1965

The 24" coil set-up will be completed and tests will start with the 960 uf capacitor bank.



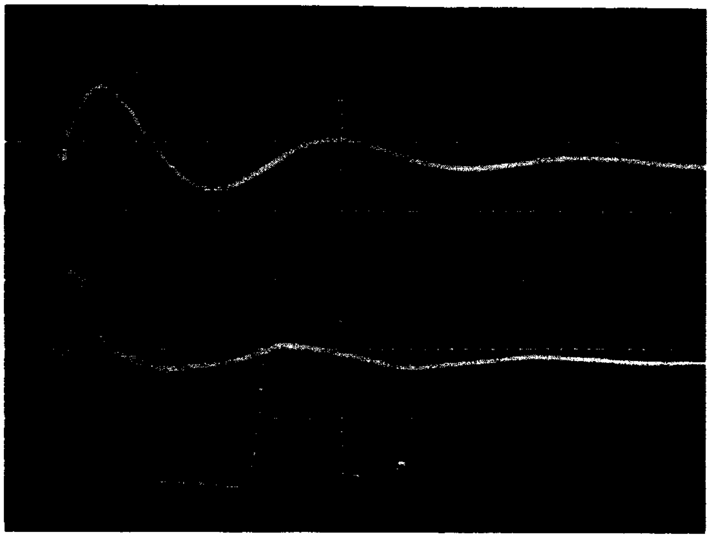
28" Dome Formed with the E. M. T. (12" Pancake Coil)

FIGURE 1



28" Domes Formed with the EBW and EMT

FIGURE 2



Capacitor Bank: 240 uf, 16 KV

Upper Trace: Current $\frac{58{,}000}{\text{cm}}$ amps, 0. 1 $\frac{\text{m sec}}{\text{cm}}$

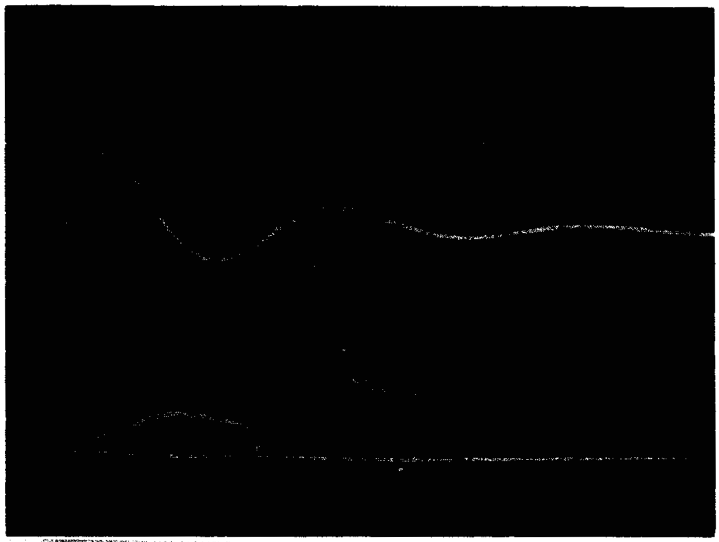
Middle Trace: Induced Voltage probe:

$\frac{40\text{V}}{\text{cm}}$ 0. 1 $\frac{\text{u sec}}{\text{cm}}$

Lower Trace: Pressure 1540 $\frac{\text{p. s. i.}}{\text{cm}}$, 0. 1 $\frac{\text{m sec}}{\text{cm}}$

E. M. T. Pressure Record

FIGURE 6



Capacitor Bank: 240 uf, 15 KV

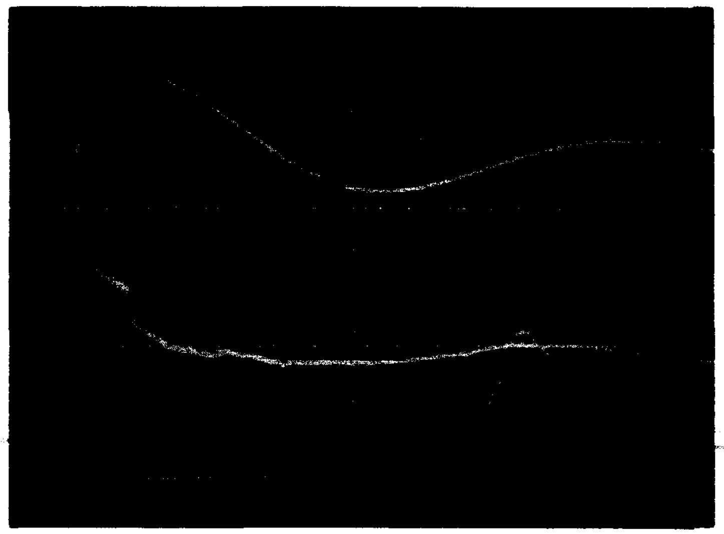
Upper Trace: Current 58,000 amps/cm $\frac{0.1 \text{ m sec}}{\text{cm}}$

Middle Trace: Pressure 1540 $\frac{\text{p. s. i.}}{\text{cm}}$ $\frac{0.1 \text{ m sec}}{\text{cm}}$

Lower Trace: Induced Voltage probe

E. M. T. Pressure Record

FIGURE 7



Capacitor Bank 240 uf 16 KV

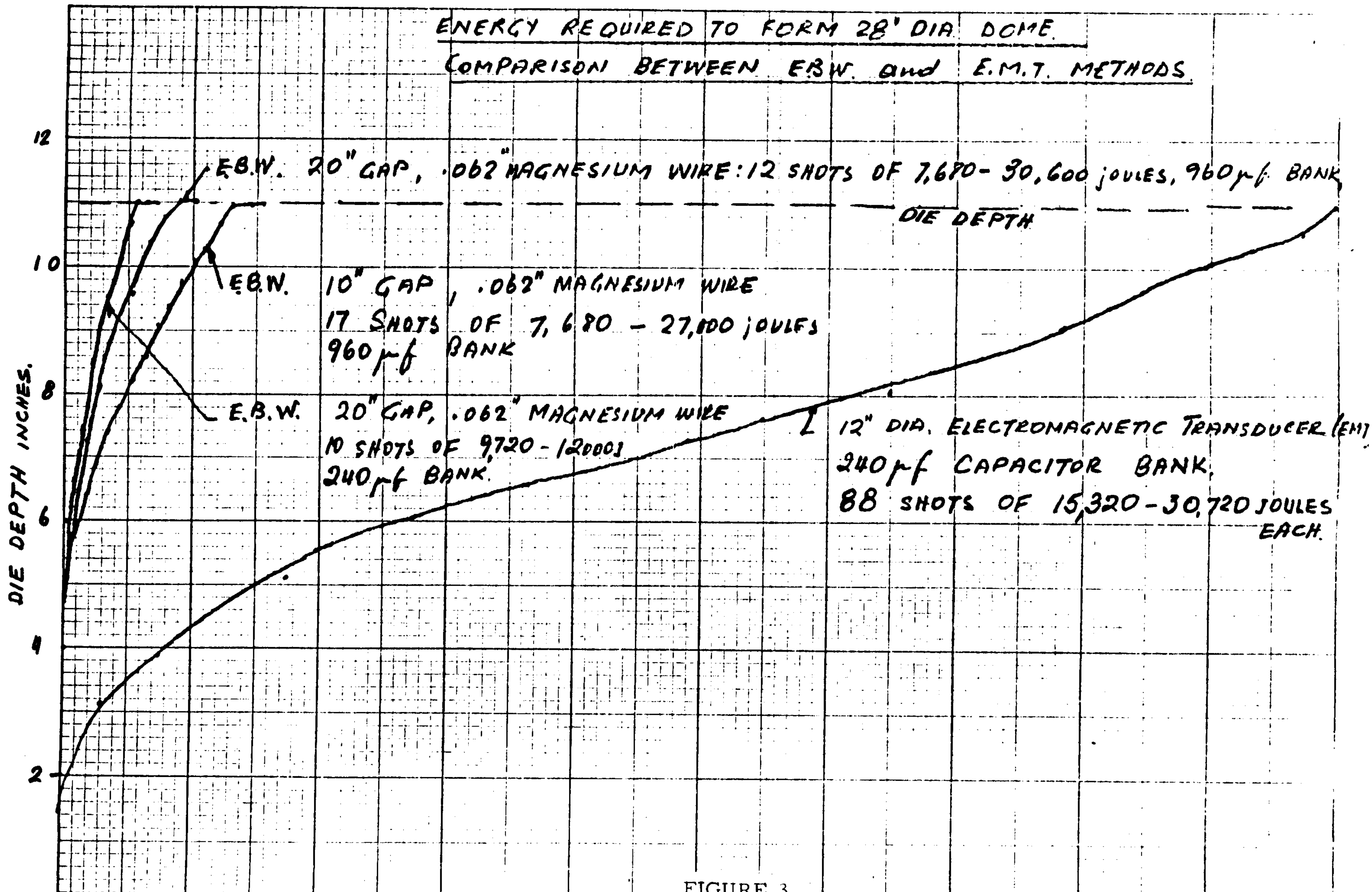
Upper Trace: Current 58,000 $\frac{\text{amps,}}{\text{cm}}$ 5.0 $\frac{\text{u sec}}{\text{cm}}$

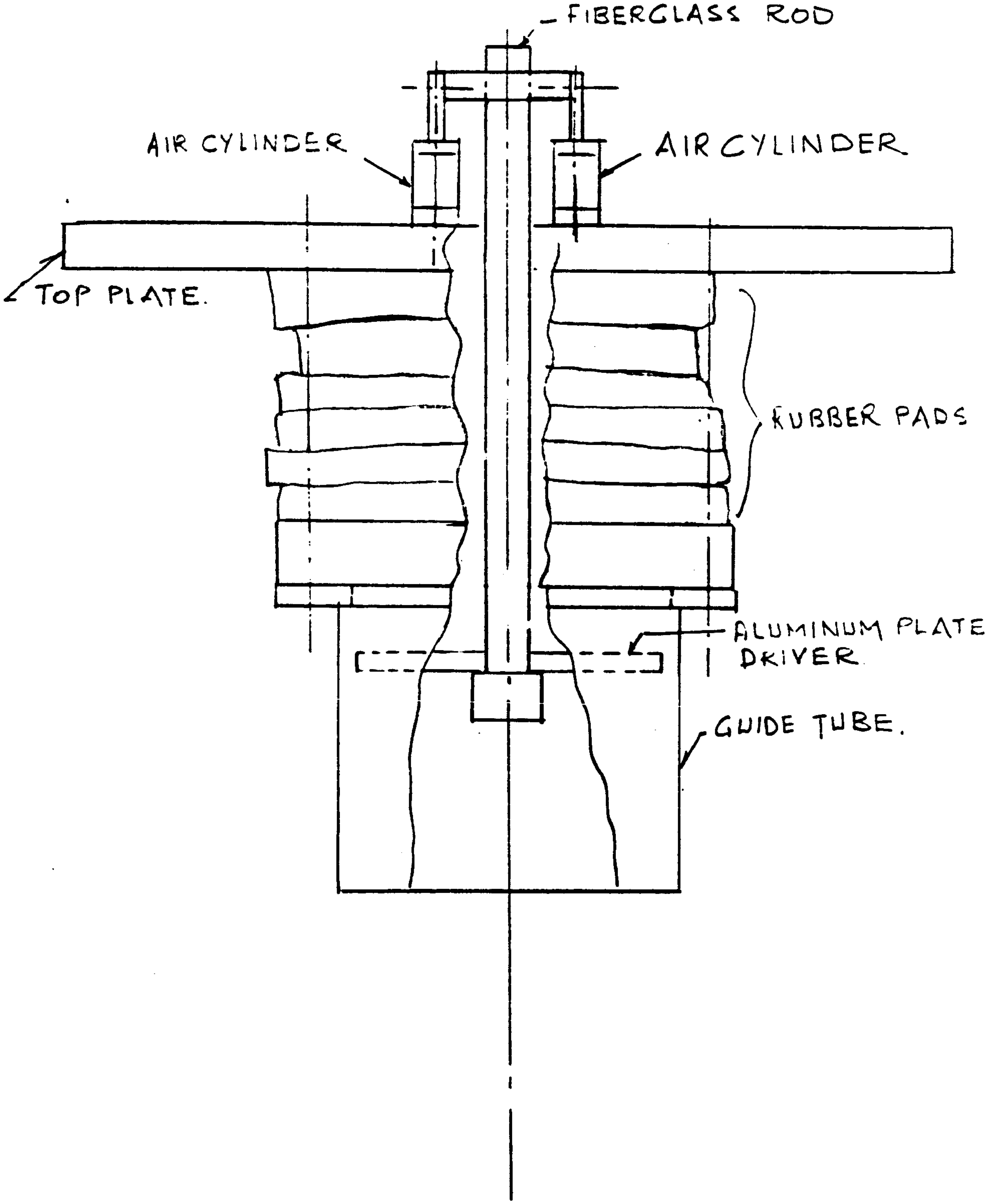
Middle Trace: Induced Voltage: 40 $\frac{\text{V,}}{\text{cm}}$ 50 $\frac{\text{u sec}}{\text{cm}}$

Lower Trace: Pressure 3900 $\frac{\text{p. s. i.,}}{\text{cm}}$ 5.0 $\frac{\text{u sec}}{\text{cm}}$

E. M. T. Pressure Record

FIGURE 8


ENERGY REQUIRED TO FORM 28" DIA DOME
COMPARISON BETWEEN E.B.W. and E.M.T. METHODS
E.B.W. 20" GAP, .062" MAGNESIUM WIRE: 12 SHOTS OF 7,680 - 30,600 joules, 960 µf BANK
DIE DEPTH
E.B.W. 10" GAP, .062" MAGNESIUM WIRE
17 SHOTS OF 7,680 - 27,000 JOULES
960 µf BANK
E.B.W. 20" GAP, .062" MAGNESIUM WIRE
10 SHOTS OF 9,720 - 12000J
240 µf BANK
12" DIA. ELECTROMAGNETIC TRANSDUCER (EMT)
240 µf CAPACITOR BANK
88 SHOTS OF 15,320 - 30,720 JOULES EACH
DIE DEPTH INCHES.
2
4
6
8
10
12
0
200
400
600
800
1000
1,200
1,400
1,600
1,800
2,000
ENERGY, JOULES × 10³
FIGURE 3



AUTOMATIC DRIVER RESETTING MECHANISM

FIGURE 4

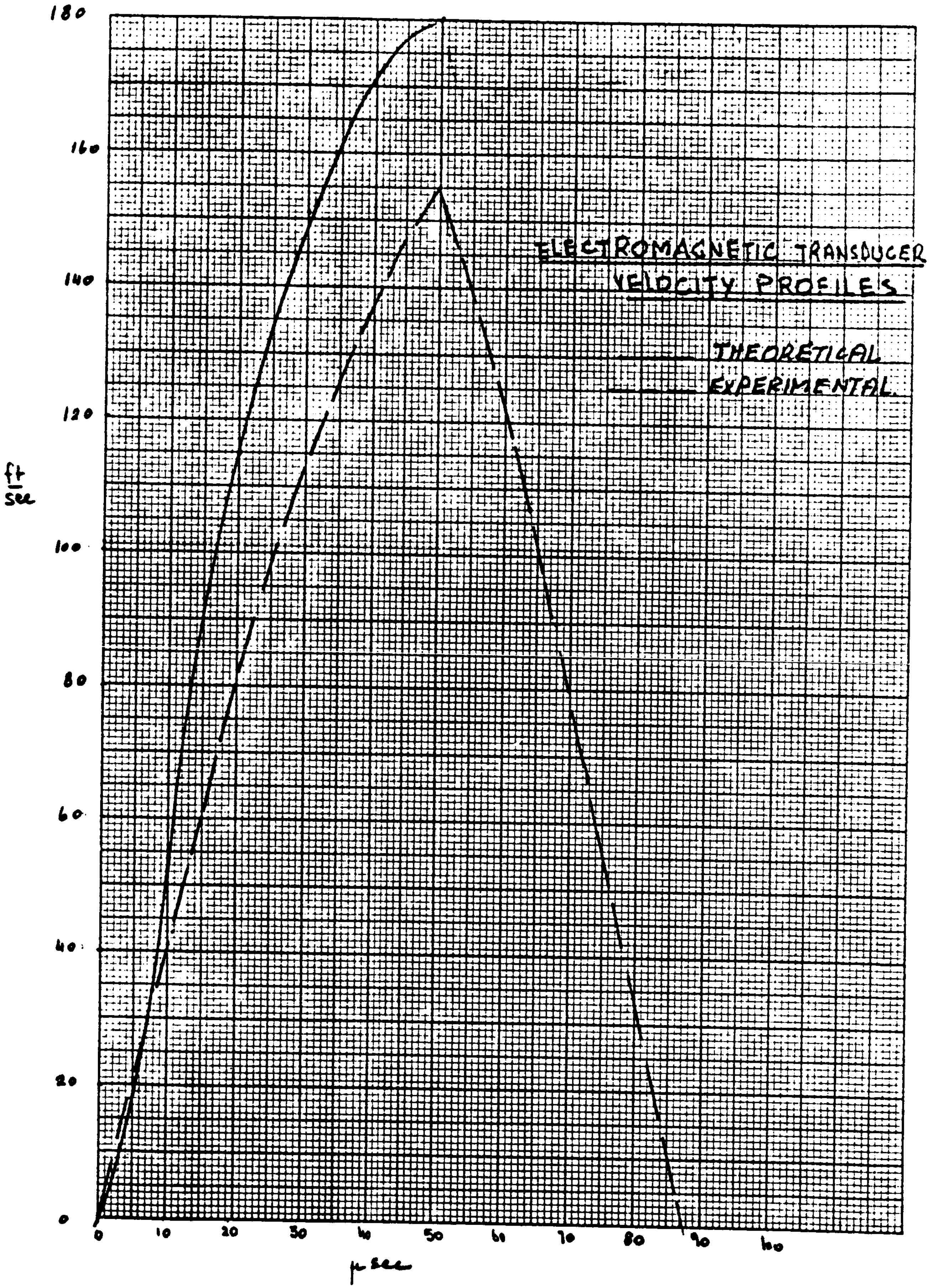
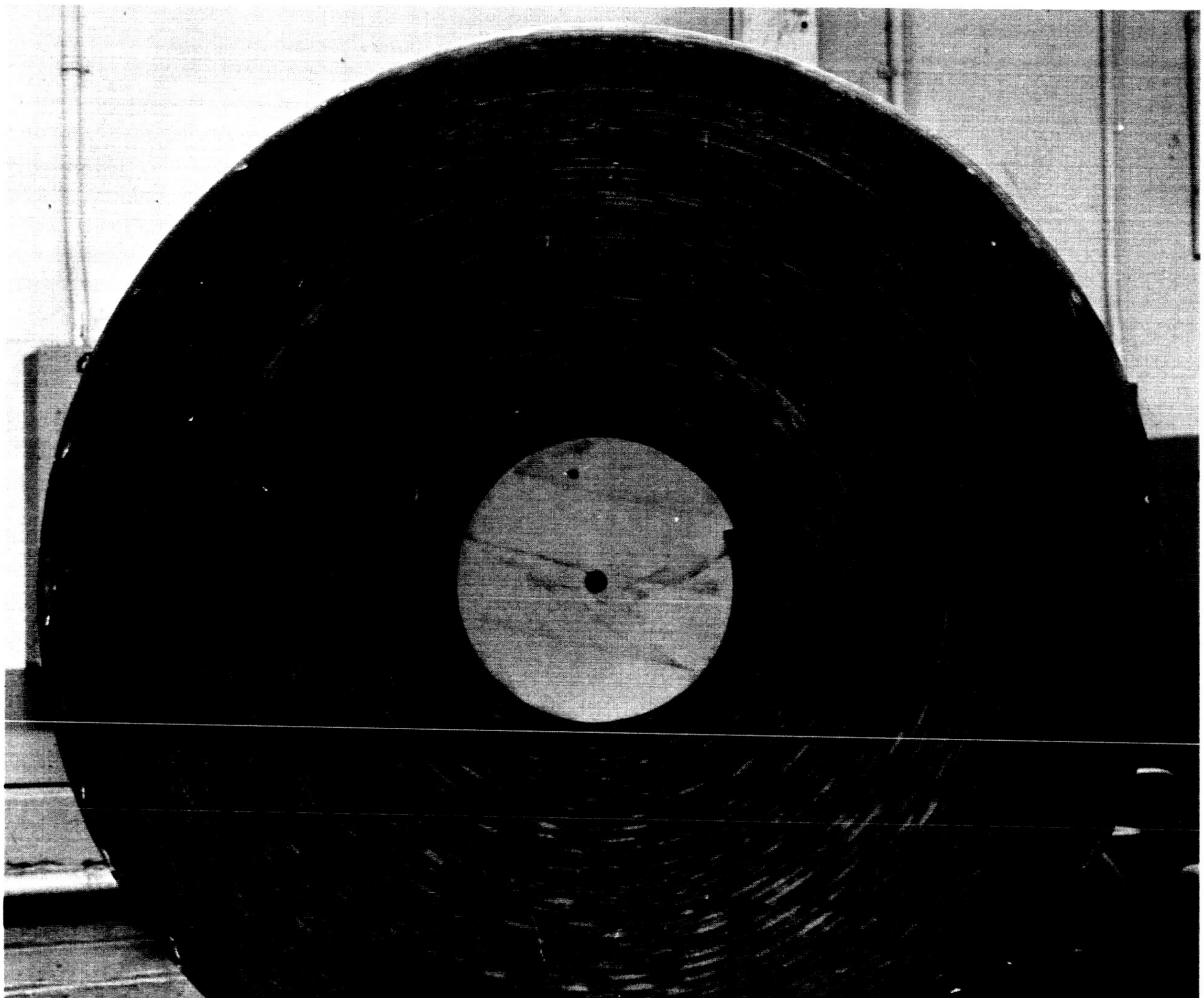
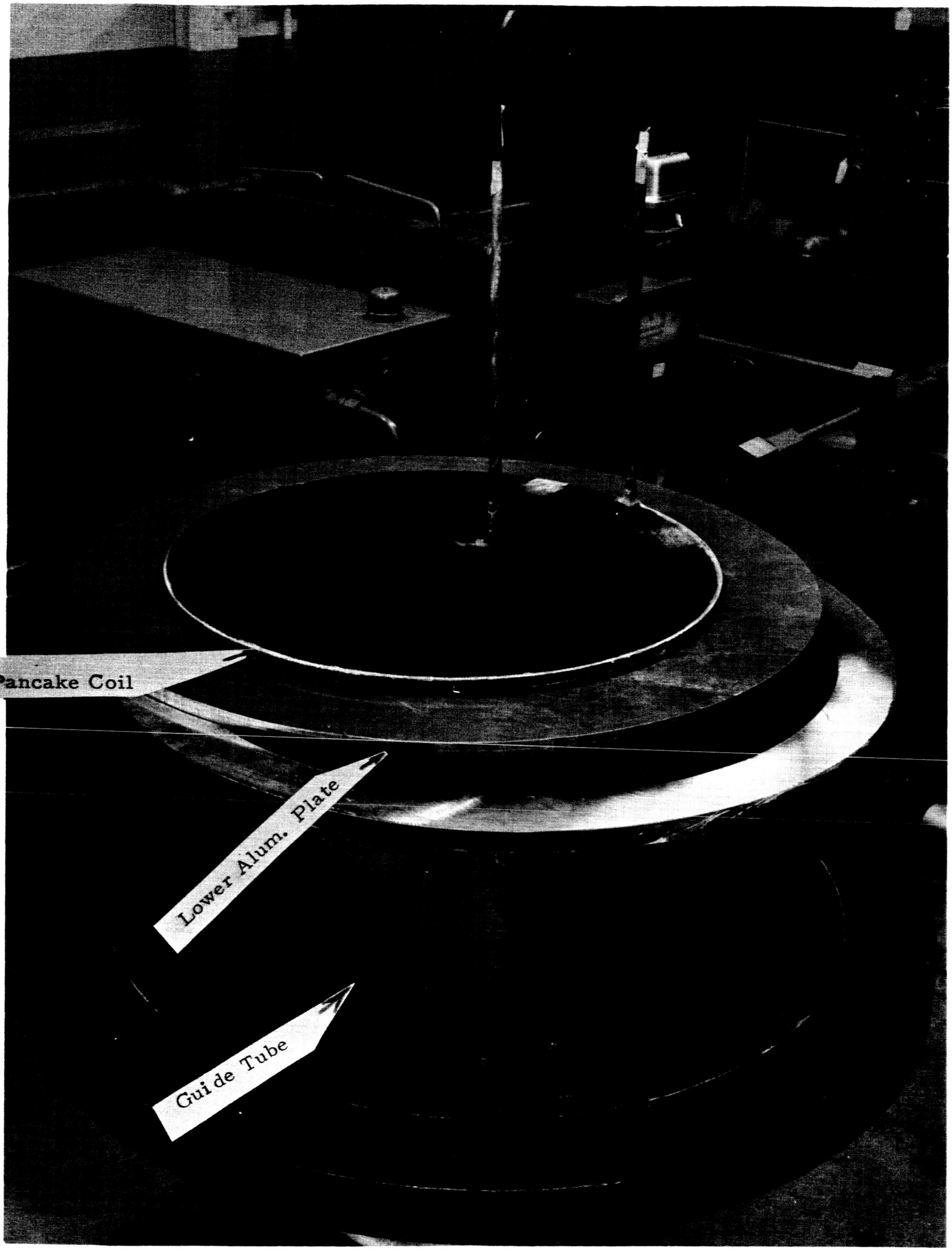

ELECTROMAGNETIC TRANSDUCER
VELOCITY PROFILES
THEORETICAL
EXPERIMENTAL
180
160
140
120
100
80
60
40
20
0
ft/sec
0
10
20
30
40
50
60
70
80
90
100
μsec

FIGURE 5



24" Pancake Coil (wire 0.500" x 0.125")

FIGURE 9



24" Pancake Coil with Lower Aluminum Plate and 24" Guide Tube

FIGURE 10